Response of Ground-dwelling Vertebrates to Thinning Young Stands: The Young Stand Thinning and Diversity Study

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INTRODUCTION

About a million hectares of mature and old-growth Douglas-fir (*Pseudotsuga menziesii*) forests in western Oregon and Washington have been converted to young plantations over the past 50 years (Debell et al. 1997). Objectives of forest management during this period emphasized the production of timber volume as rapidly (20-80 year rotations) and safely as possible. Traditional methods involved clearcut harvesting (removal of all trees and snags), burning of residual woody debris, planting of conifer seedlings at close spacing, and manual or chemical control of competing vegetation. Compared to stands regenerated after natural disturbances, these plantations noticeably lack features such as large live trees, large dead wood (snags and logs), vertical and horizontal variation in tree canopies, and a significant component of broadleaf trees (Franklin et al. 1981, Spies et al. 1988). The extent of young plantations has also led to simplified landscape structure. Plantations occupy about 25-40% of public lands managed for timber and up to 50-80% of private-industrial lands in western Oregon (Garman et al. 1999). Reduced complexity of stand and landscape structure has been attributed to the recent decline in animal populations associated with old-forest structures (Lehmkuhl and Ruggiero 1991, Ruggiero et al. 1991).

Social and political concerns for conserving biodiversity on public forests have led to substantial changes in forest-management policy in the Pacific Northwest (PNW) region (FEMAT 1993). This fundamental policy shift calls for the creation of more natural levels of complexity at both a stand and landscape scale (Swanson and Franklin 1992). Management strategies which balance commodity production and ecological diversity of existing young (20-50 year old) stands are most critical given the regional extent of plantation forests.

There is general consensus that commercial thinning can be used to increase the complexity of young plantations (Spies et al. 1991, DeBell et al. 1997, Tappeiner et al. 1997, Hayes et al. 1997). Increased light levels due to thinning can accelerate diameter growth and crown lengths of residual trees, increase development of multiple canopy layers, and promote development of ground cover. However, non-traditional thinning intensities, methods, and patterns are required to achieve these conditions. Retrospective studies have suggested that low stocking densities and irregular spacing of stems early in stand development may be most effective in enhancing the complexity of young stands (Acker et al. 1998, Tappeiner et al. 1997). Simulation experiments also have shown the ability to enhance structural complexity with non-standard thinning practices (Garman et al. in press, Garman 2001a, Barbour et al. 1997). Until recently, however, experimental investigation of trade-offs among thinning strategies, stand complexity, and biodiversity were lacking.

One of the first studies in western Oregon to examine the use of commercial thinning to enhance ecological diversity of 30-40 year-old Douglas fir stands was the Young Stand Thinning and Diversity (YSTD) Study. This study originated in the early 1990's as a cooperative effort between the Willamette National Forest and scientists from Oregon State University (Hunter 2001, www.fsl.orst.edu/ccem/yst/ystd.html). Replicated treatments examined in this study include a control (ca. 620 TPH [Trees Per Hectare]), heavy thin (123 TPH), a light thin (271 TPH), and a light thin with 20% of stand area in evenly-spaced 0.2-ha clearcut gaps. Pre-treatment (1991-93) and post-treatment (1997-2001) plant, invertebrate (200-2001 only), and vertebrate (songbirds and small mammals) data have been collected and are being analyzed (e.g., Tucker et al. 2001, Hagar and Howlin 2001, Garman 2000). This paper reports on treatment effects for ground-dwelling vertebrates 2-5 yrs after implementation of the thinning treatments.

STUDY AREA

A total of 16 Douglas-fir stands in the Willamette National Forest was used in the Young Stand Thinning and Diversity study. Replicate blocks consisting of 4 stands each are located in the Blue River Ranger District and the McKenzie Ranger District: two replicate blocks are located in the Oakridge Ranger District (Fig. 1). All stands fall within the western-hemlock *(Tsuga heterophylla*) zone (Franklin and Dyrness 1988) and originated from clearcut harvesting 35-42 years prior to the beginning of the study in 1991. Initial stocking density of stems >12.7-cm dbh (diameter at breast height) averaged 620 stems per hectare with an average dbh of 28 cm. At the initiation of the study Douglas-fir was the dominant overstory species with various amounts of western hemlock, western redcedar (*Thuja plicata*), and hardwoods such as bigleaf maple (Acer macrophyllum), golden chinkapin (*Castinopsis chrysophylla*), and red alder (*Alnus rubra*). Stands were selected for homogeneity of characteristics, such as site index (105-120), slope (0-18%), and elevation (600-900 meters). Average stand size is about 30 hectares. In each replicate block, stands were randomly assigned to one of the thinning treatments or control. Thinning began in 1994 and was completed by early 1997.

Thinning treatments were designed to emphasize different combinations of commodity production and ecological diversity. Descriptions of thinning treatments and resource goals are described below.

Heavy thin - Stand density was reduced to 123 TPH by thinning from below, and underplanted with a mixture of Douglas-fir, western hemlock, and western red-cedar within 3 years after thinning. This treatment is hypothesized to produce large trees and the greatest array of understory structure, and will determine if residual tree densities maintain wildlife species characteristic of pre-treatment conditions and if species respond to increased understory development.

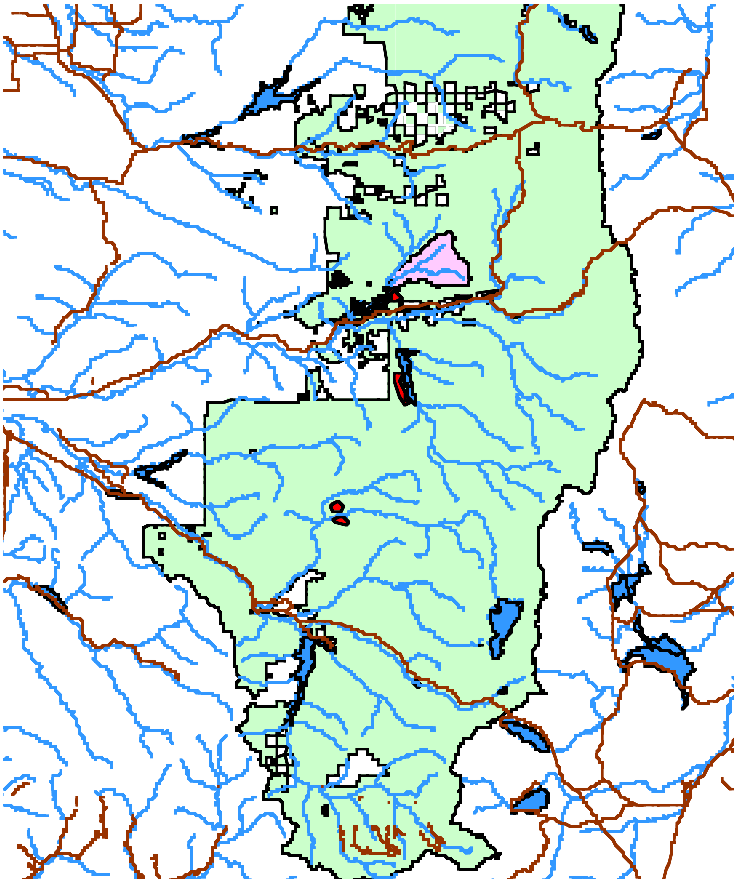

Fig. 1. Location of stands used in the Young Stand Thinning and Diversity Study, Willamette National Forest, Oregon.

Light Thin - Stand density was reduced to 271 TPH by thinning from below. This treatment represents minimum disturbance with the goal of maintaining a relatively closed canopy and keeping the stand just at the zone of imminent mortality through future thinning. This treatment is expected to produce the greatest conifer yield and least amount of understory compared to the other thinning treatments. This treatment will identify species that respond to fine-scale, uniform treatments.

Light Thin with gaps - Stand density was reduced to 271 TPH by thinning from below, but with evenly spaced 0.2-ha clearcut gaps comprising 20% of stand area. Gaps were underplanted with a mixture of Douglas-fir, western hemlock, and western red-cedar within 3 years after thinning. This treatment is the beginning of a group selection for unevenage management or a group shelterwood for evenage management, and is expected to produce diverse structure relatively quickly. This treatment will identify species that respond to a patchy distribution of different tree age/size classses.

Uncut (control) - This treatment serves as a control (ca. 620-660 TPH) for comparison with thinned stands, and also will identify species that prefer dense, closed-canopy stands.

METHODS

Vertebrate Sampling

Ground-dwelling vertebrates were sampled during the Fall (September-November) in 1991-92 (pre-treatment) and in 1998, 1999, 2001 (post-treatment). Numbers of traps and trapping design varied between the pre- and post-treatment sampling periods. In the pre-treatment sampling, a 10 x 10 grid of Sherman live-traps (7.62 x 8.89 x 22.86 cm) with 20-m inter-trap spacing was centered in each stand. Additionally, a separate 5 x 5 grid of pit-fall traps (two #10 cans stacked end-for-end) with similar spacing among traps was established in each stand. To better sample across the spatial variability of treatments, especially in the light thin with gap treatments, post-treatment sampling used variable-length transects. Number of transects in a stand varied with stand shape and size; however, each stand had a total of 100 trapping stations. Transects were spaced 30-m apart and >50-m from a stand edge. Trapping stations on a transect also were spaced 30-m apart. Pitfall traps were located at every other station for a total of 50 pitfall traps per stand. In each year of sampling, all stands of a replicate block were simultaneously trapped for 6-8 consecutive nights.

During a trapping period, one Sherman live-trap was placed at every trapping station, and pitfall traps were cleared of debris and made functional. In 2001, Tomahawk live-traps (48.26 x 15.24 x 15.24 cm) were placed at every other station on every other transect, for a total of 25 traps per stand. All traps were baited with a standard mixture of peanut butter, rolled oats, and sunflower seeds. Polyfiber batting was placed inside each trap for insulation. Sherman traps were placed inside a half-gallon milk cartons for added insulation and to reduce exposure of traps and potential captures to rain water. A pint-sized juice carton was inserted into each pitfall trap for similar reasons. Traps were checked every day. Captures were identified to species, ear-tagged or toe clipped, weighed, sexed if possible, then released immediately at the site of capture. Dead specimens were removed from the site and stored. Upon termination of a trapping period, live-traps were removed; pitfall traps were de-activated.

Analyses

The ANOVA model used to detect treatment differences of responses depended on the ability to satisfy underlying assumptions. I used a mixed-effect, repeated measures ANOVA (Proc Mixed, SAS 1990) to detect treatment and time differences for species= diversity and evenness as measured by the Shannon-Weiner Index (Krebs 1989), and for capture rates of certain species. Capture rates (no. of individuals/1000 trap nights) were based on trap preferences. In general, pitfall trapping effort was used for shrews, moles, voles, and amphibians. Trap nights for Townsend=s chipmunk and northern flying squirrel were based on both types of live-traps. Trapping effort for other rodents was based only on Sherman live-traps. Data for each year of the study were used (2 years of pre-treatment, 3 years of post-treatment) to determine treatment effects. Data were log-transformed as necessary to meet assumptions of the ANOVA model. Treatment, year, and treatment by year were fixed effects; block and block by treatment were random effects in the ANVOA. A significant treatment by year interaction indicated a treatment effect. When this interaction term was significant, additional contrasts were performed to determine treatment differences. Orthogonal contrasts evaluated differences in means between pre- and post-treatment, and between pre-treatment and each post-treatment year. If a contrast was significant, nonorthogonal contrasts were used to compare control vs. thinning-treatment means to determine specific treatment differences. A significance level of alpha= 0.05 was used for orthogonal contrasts. For nonorthogonal contrasts, Bonferroni=s adjusted probabilities (Milliken and Johnson 1992) were used to constrain the overall alpha level to 0.05. When assumptions of parametric ANOVA were not satisified, I used nonparametric methods to determine treatment differences in capture rates. I averaged data by pre- and post-treatment periods, calculated differences between treatment periods for each stand, and used the ranked differences in an ANOVA.

Abundance is sometimes a misleading indicator of habitat quality (Van Horne 1982). Areas used primarily for dispersal habitat may record more individuals but lower recapture rates compared to higher quality habitat. Also, higher relative densities in sub-optimal habitat may be dominated by younger individuals displaced from optimal habitat by older, established individuals. Gender bias also may be indicative of differential habitat suitability. To further evaluate habitat suitability, mean body mass of adults, juvenile ratio, recapture rate, and sex ratio were analyzed. Juvenile ratio was derived as the percentage of recorded, individual juveniles. Recapture rate was calculated as the number of individuals captured more than once divided by the total number of individuals and converted to a percentage. Sex ratios could not be used because not all stand-year combinations recorded both sexes. Thus, analysis of gender dominance was based on the percentage of male individuals recorded in a stand. Mean recapture rate, and juvenile and sex ratios were analyzed with the parametric ANOVA model used for analyzing capture rates. Mean body mass was analyzed with a mixed-effects, Generalized Linear Model (Proc GLM, SAS 1990). Data for this analysis consisted of all individual observations of a species in a stand. Among the five sampling years, there were some stands without records of captures or body mass, even for frequently recorded species. In the analysis of body mass, recapture rate, and juvenile and sex ratio, data were combined for the pre- and post-treatment periods. Thus, the year term in the ANOVAs simply equated to before and after thinning treatment. Even with this simplification, only certain species had suitable sample sizes for meaningful statistical analyses.

To determine treatment effects on resource partitioning, spatial overlap among ecologically similar species was evaluated with Horn's index (Horn 1966). For each pairwise combination of species, numbers of trapping stations recording just one of the species and both species were used in calculating the index. Spatial overlap was calculated only for the three post-sampling years. The mixed-effects parametric ANOVA model was used to determine treatment effects. To determine overlap greater than expected, observed overlap measures were compared to Monte Carlo simulations that were based on observed sample sizes.

RESULTS

A total of 7847 captures were made of 13 species of small mammal, two mustelids (short-tailed weasel and spotted skunk), one marsupial, one hare, and nine species of amphibians (Table 1). Additionally, incidental captures of a long-tailed and a Richardson=s vole, and a vagrant and a Baird=s shrew were recorded, but species identification is questionable. Dominance of species varied among treatment periods. The deer mouse, Trowbridge=s shrew, and western red-backed vole accounted for 43, 23, and 14% of individuals, respectively, in the pre-treatment period. In the post-treatment period, the Townsend=s chipmunk, Trowbridge=s shrew, and deer mouse accounted for 33, 30, and 29% of recorded individuals, respectively. Enstaina was the most dominant amphibian species recorded, accounting for 70-77% of amphibian captures in both treatment periods.

Temporal trends in capture rates illustrate the inherent variability in densities of vertebrates (Fig. 2). In general, captures were higher in 1998 compared to pre-treatment levels for the deer mouse, ensatina, Trowbridge=s shrew, fog shrew, and Townsend=s chipmunk. For all but the chipmunk, relative densities of these noticeably decreased in 1999. Densities of the deer mouse, ensatina, and fog shrew remained low in 2001. Densities of the Trowbridge=s shrew and Townsend=s chipmunk increased between 1999 and 2001. The red-backed vole noticeably declined after 1992 across all treatments for unknown reasons. However, similar declines have been documented over this time period in 80-yr-old stands on other portions of the Willamette National Forest (Garman 2001b). Of the more commonly captured species, only the northern flying squirrel was apparently eliminated due to thinning. In 1998-99 and 2001, no flying squirrels were recorded on the heavy-thin treatment, and post-treatment capture rates were nominal on other treatments compared to the uncut control. Of the mammal species with at least 20 captures over the course of this study, the shrew-mole was the only species not recorded in all treatment types prior to thinning (Fig. 2).

Six species were recorded only after thinning (Table 1); however, numbers of captures were too limited for meaningful analyses. The bushy-tailed wood rat, snowshoe hare, and opossum were each recorded on only one stand. The Douglas=s squirrel was often heard in control stands during trapping; however, few were ever trapped. All eight captures of the California ground squirrel were recorded on two adjacent stands in the Christy Flats block and in Tomahawk traps. The noticeable increase in captures of the spotted skunk was due to the use of Tomahawk traps in 2001. Prior to 2001, this species was not recorded in the post-treatment period (Garman 2000).

Table 1. Numbers of marked individuals and total captures by species, by pre- and post-treatment sampling periods, Young Stand Thinning and Diversity Study. Pre-treatment sampling was conducted Fall 1991-92; post-treatment sampling was conducted Fall 1998-99, 2001.

MAMMALS

	Pre-treatment		Post-treatment	
Species	No. individuals	No. captures	No. individuals	No. captures
Coast mole	7	8	7	8
Shrew-mole	6	6	20	20
Marsh shrew	2	2	2	2
Sorex[1]	5	6	1	1
Fog shrew	115	126	170	180
Trowbridge=s shrew	378	396	1200	1225
Western red-backed vole	229	307	46	52
Microtus spp[2]	2	2	0	0
Creeping vole	18	19	68	74
Bushy-tailed wood rat	0	0	3	4
Deer mouse	725	1610	1169	2451
Townsend=s chipmunk	137	285	1325	3357
California ground squirrel	0	0	8	8
Northern flying squirrel	44	63	40	55
Douglas=s squirrel	0	0	3	3
Short-tailed weasel	3	3	3	3
Western spotted skunk	1	1	-[3]	42
Snowshoe hare	0	0	1	1
Virginia opossum	0	0	1	1
Total Mammals	1672	2834	4067	7487

Table 1. Cont=d.

AMPHIBIANS

Species	Pre-treatment No. individuals	Pre-treatment No. captures	Post-treatment No. individuals	Post-treatment No. captures
Northwestern salamander	4	4	9	9
Clouded salamander	2	3	0	0
Pacific giant salamander	1	1	5	5
Ensatina	41	41	109	109
Dunn=s salamander	1	1	1	1
Rough-skinned newt	4	4	27	27
Red-legged frog	0	0	3	3
Tailed frog	0	0	1	1
Western toad	0	0	1	1
Total Amphibians	53	54	156	156

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[1] Questionable identification - recorded as Baird=s and vagrant shrews

[2] Questionable identification - recorded as long-tailed and Richardson=s voles

[3] Skunks were not marked, thus number of individuals could not be determined

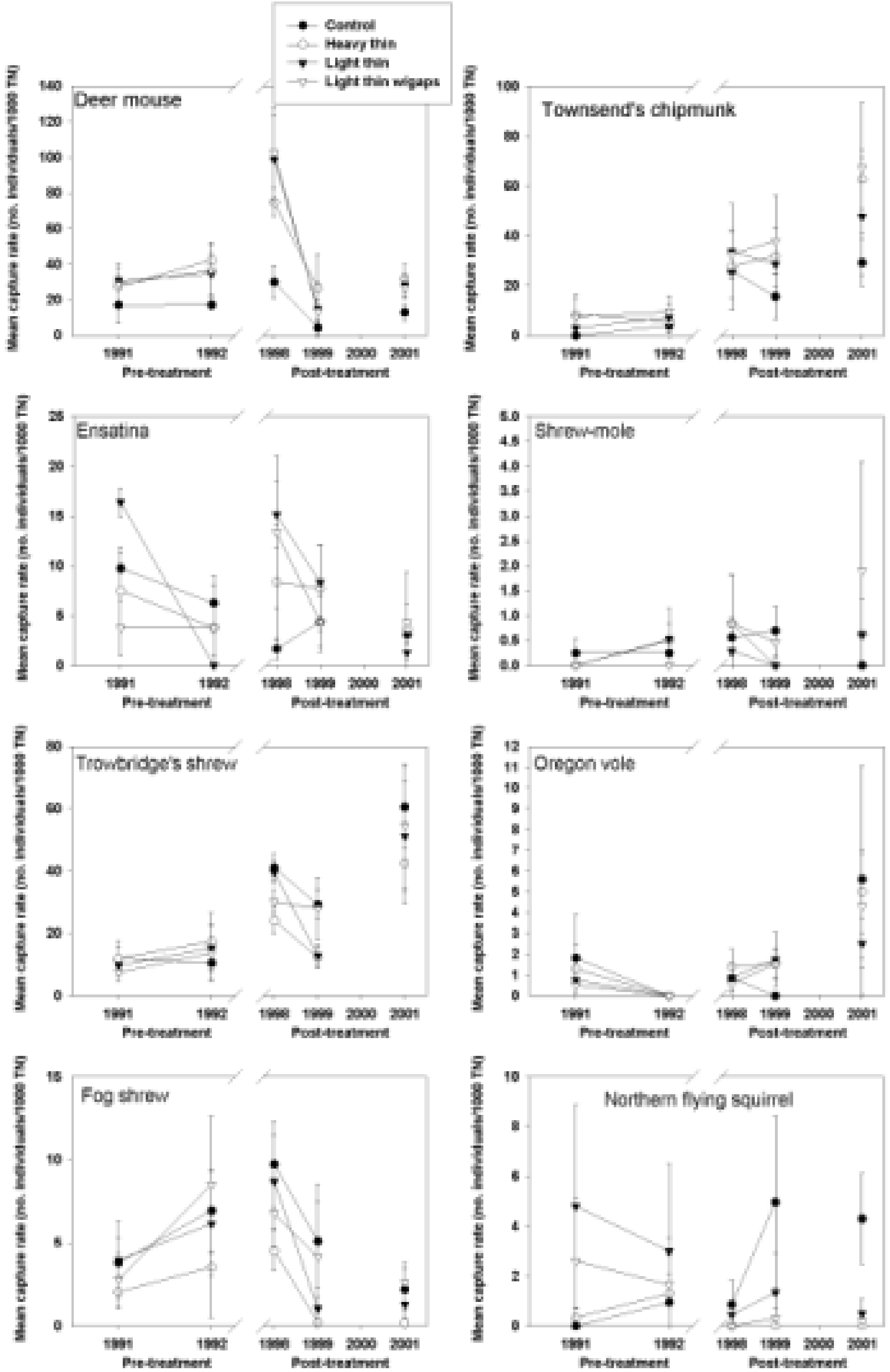

Fig. 2. Mean (± 1 SE) capture rate for selected small mammals and ensatina, Young Stand Thinning and Diversity Study.

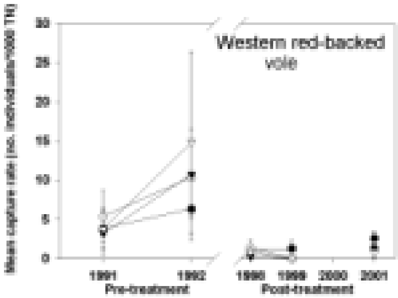

Fig. 2. Cont'd.

ANOVA Results

Capture Rates

Only seven small mammal and one amphibian species had suitable sample sizes for meaning analysis of capture rates. Of these, treatment effects of five of these species were analyzed with the parametric ANOVA (Table 2). Of these, the deer mouse, ensatina, and Trowbridge=s shrew exhibited a statistically significant numerical response to thinning treatments (Table 2). The relative abundance of the deer mouse and ensatina increased in the two light thin treatments in 1998. Treatment effects were not significant thereafter for either species. The Trowbridge=s shrew exhibited the strongest, consistent response to thinning. Capture rate of this species was significantly lower in the heavy thin treatment in 1998-99 compared to the control. In 2001, treatment effects were not longer apparent for this species. Although treatment effects were not significant for the Townsend=s chipmunk, densities of this species were 2-3 times greater on the heavy-thin and gap treatments compared to the uncut control in 2001.

Treatment effects were examined with non-parametric ANOVA for four species of small mammal. Treatment effects were not significant ($F_{3,12}$, *P*=s >0.73) for the red-backed vole, shrew mole, and creeping vole. Captures of the northern flying squirrel significantly (*P*=0.008) declined on the thinning treatments (e.g., Fig. 2), but were not significantly different (*P*>0.05) among thinning treatments.

Table 2. Repeated measures ANOVA and contrasts of ground-dwelling species capture rates (no. individuals/1000 TN), Young Stand Thinning and Diversity Study. Pre-treatment sampling was conducted 1991-92; post-treatment sampling was conducted 1998-99 and 2001.

		P values for Pre - Post treatment contrast				*P* values for Pre - 1998 Post treatment contrast			
	Treatment X Year		Contrast of CN* with:				Contrast of CN* with:		
Species	*P*	Pre - Post	HT	LT	LTw/gaps	Pre - 1998	HT	LT	LTw/gaps
Deer mouse	0.049	0.493	-	-	-	0.003	0.090	0.002	0.001
Ensatina	0.045	0.172	-	-	-	0.018	0.080	0.003	0.003
Trowbridge=s shrew	0.036	0.016	0.002	0.106	0.394	0.040	0.011	0.711	0.188
Fog shrew	0.929	-	-	-	-	-	-	-	-
Townsend=s chipmunk	0.902	-	-	-	-	-	-	-	-

	P values for Pre - 1999 Post treatment contrast				*P* values for Pre - 2001 Post treatment contrast			
		Contrast of CN* with:				Contrast of CN* with:		
Species	Pre - 1999	HT	LT	Ltw/gaps	Pre - 2001	HT	LT	LTw/gaps
Deer mouse	0.896	-	-	-	0.997	-	-	-
Ensatina	0.719	-	-	-	0.483	-	-	-
Trowbridge=s shrew	0.013	0.010	0.052	0.948	0.389	-	-	-
Fog shrew	-	-	-	-	-	-	-	-
Townsend=s chipmunk	-	-	-	-	-	-	-	-

NOTE: for contrasts; df = 12,48 for Treatment X Year interaction; df=3,48 for Pre - Post and Pre- 1998, 1999, 2001 contrasts; df=1,48 for contrasts of CN with the 3 thinning treatments.

* CN = control; HT = heavy thin; LT = light thin; LTw/gaps = light thin with gaps.

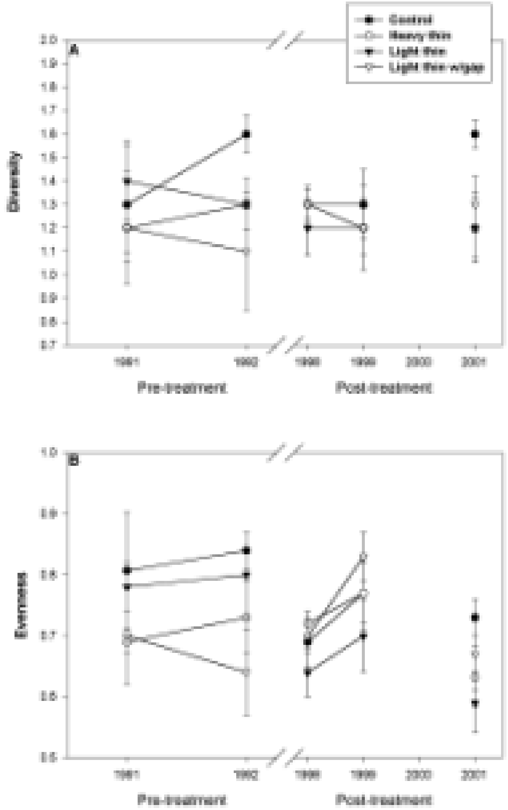

Fig. 3. Mean (± 1SE) species' diversity (A) and evenness (B) for small-mammal species by treatment and by year, Young Stand Thinning and Diversity Study.

Community Measures

Diversity and evenness measures were derived using only the positively identified small mammal species - the limited data for amphibians prohibited meaningful analysis. There were no significant treatment effects ($F_{12,48}$ *P*=s >0.22) for either community measure (Fig. 3). Mean diversity and evenness were generally higher on the control stands compared to the other treatments in especially 2001. However, for some unknown reason, these measures generally were higher on the control even in the pre-treatment phase. Evenness on all treatments somewhat declined in 2001 compared to other years. This was generally due to the dominance of the Townsend=s chipmunk and Trowbridge=s shrew in 2001 (Fig. 2).

Recapture Rate, Juvenile and Sex Ratio, and Body Mass

There were no detectable significant (*P*'s > 0.2) treatment effects on these measures (Tables 3-6). General trends included fairly consistent mean body mass among treatment periods (pre-, post- treatment) for all species considered (Table 3). Recapture frequency increased by a factor of 2-3 between periods for all species examined except the deer mouse, but increases were proportionally similar among the control and thinning treatments (Table 4). Juveniles were more common in the post-treatment period for the Townsend=s chipmunk and fog shrew, and less common for the Trowbridge=s shrew across all treatments (Table 5). Mean male ratios were highly variable among treatments and sampling periods for the two species examined (Table 6). The overall lack of significant treatment effects for these measures suggests that numerical responses observed in this study most likely reflected habitat quality.

Spatial Overlap

Spatial overlap was analyzed only for two pairs of ecological similar species (Table 7). Overlap between the deer mouse and Townsend=s chipmunk was considered because of their affinity for similar food resources. Spatial pattern of the congeneric species of *Sorex* was considered because species have similar habits and ecological function. For both pairs of species, there was no significant treatment effect ($F_{6,24}$, *P*=s >0.79) on spatial overlap. Spatial overlap between the two rodents was higher and more variable among treatments and years than overlap between the *Sorex* species. Compared to the rodents, lower overlap values for the shrew species reflected more extreme differences in relative densities. Annual trends in spatial overlap paralleled numerical trends of species. Similar values of overlap between 1998 and 2001 for the two rodents reflected the high densities of deer mice in 1998 and the high densities of chipmunks in 2001 (q.v. Fig. 2). Spatial overlap values for the shrew species exhibited a somewhat similar trend.

Simulated overlap values were generally higher for the rodents, but most observed and simulated values were not significantly different (*P* >0.05) based on paired t-tests. However, observed overlap values were significantly greater (*P* <0.05) than expected based on chance on thinned stands in 2001. Simulated overlap values for the shrew species were generally lower than observed values but most were not significantly different. Observed overlap was actually greater than expected by chance for at least one treatment type each year. For both pairs of species, these results fail to show the importance of spatial partitioning among species as well as differences in spatial partitioning among treatment types.

Table 3. Mean (± 1SE) weight of adult individuals before and after thinning treatments., Young Stand Thinning and Diversity Study. Pre-treatment means based on combined data from 1991-92; post-treatment means based on combined data from 1998-99 and 2001.

	Deer mouse		Townsend=s chipmunk		Trowbridge=s shrew		Fog shrew	
Treatment	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Control	18.6 ± 0.42 (57)	18.4 ± 0.27 (64)	85.0 ± 2.00 (9)	91.0 ± 0.82 (59)	5.3 ± 0.12 (30)	5.3 ± 0.05 (143)	6.6 ± 0.40 (39)	6.8 ± 0.17 (55)
Heavy thin	18.3 ± 0.23 (109)	18.4 ± 0.25 (131)	89.9 ± 1.68 (25)	90.8 ± 0.51 (145)	5.1 ± 0.09 (34)	5.3 ± 0.05 (99)	6.0 ± 0.48 (22)	6.3 ± 0.22 (15)
Light thin	17.8 ± 0.26 (103)	18.1 ± 0.15 (195)	91.2 ± 2.16 (25)	89.8 ± 0.52 (99)	5.8 ± 0.89 (17)	5.3 ± 0.07 (105)	6.7 ± 0.38 (38)	6.4 ± 0.20 (31)
Light thin w/g	18.4 ± 0.23 (118)	18.4 ± 0.21 (146)	88.8 ± 0.86 (28)	90.9 ± 0.50 (130)	5.6 ± 0.34 (27)	5.4 ± 0.08 (92)	7.2 ± 0.67 (36)	6.2 ± 0.19 (39)

Table 4. Mean (± 1SE) percentage of individuals recaptured for four species of small mammals, Young Stand Thinning and Diversity Study. Pre-treatment means based on combined data from 1991-92; post-treatment means based on combined data from 1998-99 and 2001.

	Deer mouse		Townsend=s chipmunk		Trowbridge=s shrew		Fog shrew	
Treatment	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Control	46.9 ± 5.5	49.5 ± 4.7	29.5 ± 28.9	56.4 ± 2.9	2.0 ± 1.4	3.2 ± 0.4	5.3 ± 3.5	17.5 ± 3.2
Heavy thin	50.7 ± 1.9	48.9 ± 2.6	32.5 ± 20.3	50.3 ± 4.8	1.0 ± 0.7	3.4 ± 1.7	0.0	20.2 ± 9.3
Light thin	43.4 ± 5.2	53.1 ± 3.4	29.8 ± 12.4	47.1 ± 8.9	1.4 ± 1.0	4.1 ± 1.1	13.9 ± 13.9	12.4 ± 6.8
Light thin w/gaps	47.1 ± 3.3	43.7 ± 3.7	22.4 ± 9.9	55.8 ± 4.2	0.4 ± 0.5	3.1 ± 0.6	2.3 ± 2.6	6.1± 4.2

Table 5. Mean (± 1SE) percentage of individual juveniles for four species of small mammals, Young Stand Thinning and Diversity Study. Pre-treatment means based on combined data from 1991-92; post-treatment means based on combined data from 1998-99 and 2001.

	Deer mouse		Townsend=s chipmunk		Trowbridge=s shrew		Fog shrew	
Treatment	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Control	53.4 ± 14.1	45.2 ± 7.8	45.0 ± 30.3	56.9 ± 11.9	71.8 ± 16.8	43.2 ± 11.5	7.1 ± 8.0	3.1 ± 2.2
Heavy thin	59.3 ± 6.2	57.5 ± 9.5	52.5 ± 21.7	68.2 ± 8.2	77.2 ± 12.7	41.6± 11.9	0.0	10.0 ± 11.0
Light thin	57.4 ± 8.6	36.9 ± 11.4	26.2 ± 19.2	68.8 ± 12.9	86.7 ± 12.2	46.0± 13.8	2.5 ± 2.8	10.8 ± 9.1
Light thin w/gaps	51.0 ± 6.4	53.4 ± 10.7	62.9 ± 25.2	67.9 ± 8.8	73.7 ± 16.6	63.9 ± 9.1	0.0	12.9± 10.9

Table 6. Mean (± 1SE) percentage of individual males of two species of small mammals, Young Stand Thinning and Diversity Study. Pre-treatment means based on combined data from 1991-92; post-treatment means based on combined data from1998-99 and 2001.

	Pre-treatment				Post-treatment			
Species	Control	Heavy	Light	Light/gaps	Control	Heavy	Light	Light/gaps
Deer mouse	55 (4.4)	48 (5.4)	54 (6.7)	51 (5.4)	36 (9.2)	40 (1.4)	47 (1.3)	46 (4.0)
Townsend=s chipmunk	20 (28.3)	74 (15.8)	20 (16.3)	61 (24.5)	50 (5.8)	44 (6.3)	39 (4.3)	41 (0.6)

Table 7. Mean (± 1SE) percentage of spatial overlap between selected pairs of small mammals in the three post-treatment years, Young Stand Thinning and Diversity Study.

	Deer mouse and Townsend=s chipmunk			Trowbridge=s and Fog shrew		
Treatment	1998	1999	2001	1998	1999	2001
Control	15.7 ± 10.6	9.1 ± 6.4	21.7 ± 10.4	13.6 ± 6.9	13.0 ± 8.7	12.5 ± 10.5
Heavy thin	40.3 ± 6.8	23.7 ± 4.2	41.7 ± 3.1*	10.6 ± 5.5*	12.6 ± 1.5*	1.4 ± 1.7
Light thin	29.3 ± 13.2	7.5 ± 3.4	32.9 ± 9.1*	11.1 ± 6.0	0.0 ± 0.0	7.1 ± 5.3*
Light thin w/gaps	38.9 ± 4.9	21.4 ± 9.1	37.7 ± 5.1*	12.0 ± 1.6*	9.7 ± 4.5	6.6 ± 3.0*

* observed values significantly (P <0.05) lower than expected due to chance

DISCUSSION

Community Structure

Thinning young Douglas-fir stands had little impact on the diversity and evenness of the small mammal community. Of the nine more commonly captured mammal species, the shrew-mole was the only species which first appeared in a set of treatment stands after thinning. Its absence in the light-thin with gap stands prior to thinning, however, was likely a sampling artifact. Numbers of captures of this species were limited in all treatments and years, and it was recorded prior to thinning in stands similar and spatially adjacent to those assigned to the gap treatments. Only the northern flying squirrel was apparently eliminated from a thinning treatment. Relative abundance of the northern flying squirrel generally declined with thinning, especially in the heavy thin treatment where it was not recorded in any of the three post-treatment sampling years. Reduction of flying squirrel densities with overstory removal would be expected given dependence of this arboreal species on trees for nesting and resting (Carey 1991, 1995). Given that ground-based traps are not optimal for recording this species, however, the apparent elimination of the flying squirrel from the heavy-thin stand should be viewed with some caution.

Species= Relative Abundance

Of the nine species analyzed, only the deer mice and ensatina exhibited a positive response to thinning treatments, and this response was evident only in 1998. The deer mouse especially was expected to respond to thinning treatments. This species is a habitat generalist with an extensive range in western Oregon (Csuti et al. 1997). Although equal preference for forested and clearcut areas have been documented for the deer mouse (Sullivan 1979, Cole et al. 1998), most studies have found this species to be most commonly associated with open-canopy conditions (Gashwiler 1970, Hooven 1973, Galindo and Krebs 1985). Ensatina is an upland species (Gomez 1992, McComb et al. 1993a,b) and is also found throughout western Oregon in Douglas-fir forests (Csuti et al. 1997). Studies have found abundance of this species to be similar among a range of forest age classes (Corn and Bury 1991, Gilbert and Allwine 1991), but inversely related to moisture conditions (Aubry and Hall 1991, Gilbert and Allwine 1991, Welsh and Lind 1991). Differences in hardwood basal area among thinning treatments in addition to climatic factors were initially offered as an explanation for the numerical trends of the deer mouse and ensatina in 1998-99 (Garman 2000). However, the consistent lack of treatment effects since 1999 suggests that the 1998 response may just reflect a short-term although prominent influx of individuals onto treated stands. Aggregate assessments of juvenile, gender, adult body mass, and capture frequency failed to numerical responses

The shrew species analyzed are denizens of mid to late-seral coniferous forests in the Pacific Northwest (Whitaker and Maser 1976; Brown 1985). Decaying litter and shrub cover are important habitat features for these species (Hooven and Black 1976, Whitaker and Maser 1976). The heavy thin treatment reduced shrub cover due to incidental removal and damage during logging (Garman 2000). Surface-litter depth also was likely reduced due to compaction during thinning operations or due to higher decay rates afforded by the more open and warmer conditions. The reduction of these or other features was evidently sufficient for a consistent decrease in relative abundance of the Trowbridge=s shrew in 1998-99 on the heavy-thin treatment. The neutral response of this shrew to the heavy-thin treatment in 2001, however, suggests recovery of ground-level conditions. Reasons why the fog shrew did not respond in a similar manner is unclear. Both species of shrew have similar habitat and other resource needs. Evidenced by the spatial overlap assessment, interspecific competition did not appear to influence the distribution or densities of either species.

The lack of a significant response by other species to thinning treatments occurred for several possible reasons. An obvious reason is that although thinning noticeably affected stand conditions, key habitat features for certain species may have remained sufficiently unaltered. For instance, the Townsend=s chipmunk is generally found in forest or shrub-edge habitats (Brown 1985). Small mammal studies in clearcuts have found this species to decrease in numbers with the removal of the forest canopy and subsequently increase in abundance with the development of a tall-shrub layer (Gashwiler 1970, Hooven and Black 1976). Additionally, this species has been found to be relatively abundant in younger stands with a diverse understory and relatively high levels of residual woody debris (Doyle 1990, Rosenberg and Anthony 1993, Carey 1995). Although tree and shrub cover were reduced on the treated stands in this study, cover components were not totally eliminated. Also, there is no evidence that log cover was influenced by thinning treatments. Given that the Townsend=s chipmunk exhibited a neutral response to the thinning treatments, residual levels of these and other habitat features were evidently sufficient among treatments to maintain chipmunk densities comparable to untreated conditions.

Another reason is that interactions among key habitat features may have confounded species= response to treatments. The creeping vole prefers grass-forb areas and has been found to be common in clearcuts after the reestablishment of ground cover (Hooven 1973, Corn and Bury 1981, Sullivan and Boateng 1996). Although herbaceous cover increased in treated stands, other ground covering features such as moss and low shrubs decreased. The net effect may have been a limited change in habitat quality. As ground and shrub cover develop in the thinned stands, however, abundance of this species is likely to increase.

Population declines independent of habitat quality also affected the ability to detect treatment effects. This was especially true for the western red-backed vole. This species prefers moist microclimates of closed-canopy forests and negatively responds to the loss of overstory and log cover (Gomez 1992, Doyle 1987). Abundance was expected to decline especially on the heavy-thin treatment. However, the overall decline in relative abundance of this vole in the post-treatment period effectively prohibited a meaningful assessment of treatment effects.

SUMMARY

The thinning treatments examined in this study had little influence on the structure and composition of the ground-dwelling vertebrate community. Based on three years of post-treatment sampling, the deer mouse and ensatina were the only species to exhibit a positive treatment effect. However, this effect was evident only 1-2 years after thinning. The Trowbridge=s shrew exhibited a negative response to the heavy-thin treatment, likely due to the loss of shrub and ground cover. In 2001, however, there were no detectable treatment effects for this species suggesting recovery of ground-cover conditions by this time. The northern flying squirrel was the only species eliminated by a thinning treatment. No observations of this species have been recorded on the heavy-thin stands in the post-treatment phase of the study. Thinning, in general, resulted in significantly lower densities of this species compared to the uncut control stand. The Townsend=s chipmunk is the only species which appears to have a delayed, positive response to thinning. Although treatment effects were not significant for this species, mean densities on the heavy-thin and gap treatments were about three-times greater than on the uncut control in 2001. However, continued monitoring is critical to determine if this species is in fact responding to vegetative development on these heavier thinned treatments.

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Appendix A. Common and latin names of ground-dwelling vertebrate species recorded in the Young Stand Thinning and Diversity Study.

Baird's shrew	*Sorex bairdi*
Bushy-tailed wood rat	*Neotoma cinerea*
California ground squirrel	*Spermophilus beecheyi*
Clouded salamander	*Aneides ferreus*
Coast mole	*Scapanus orarius*
Creeping vole	*Microtus oregoni*
Deer mouse	*Peromyscus maniculatus*
Douglas' squirrel	*Tamiasciurus douglasii*
Dunn's salamander	*Plethodon dunni*
Ensatina	*Ensatina eschscholtzii*
Ermine (short-tailed weasel)	*Mustela erminea*
Fog shrew	*Sorex sonomae*
Long-tailed vole	*Microtus longicaudus*
Marsh shrew	*Sorex bendirii*
Northern flying squirrel	*Glaucomys sabrinus*
Northwestern salamander	*Ambystoma gracile*
Pacific giant salamander	*Dicamptodon tenebrosus*
Red-legged frog	*Rana aurora*
Richardson's/water vole	*Microtus richardsoni*
Rough-skinned newt	*Taricha granulosa*
Shrew-mole	*Neurotrichus gibbsii*
Snowshoe hare	*Lepus americanus*
Tailed frog	*Ascaphus truei*
Townsend's chipmunk	*Tamias townsendii*
Trowbridge's shrew	*Sorex trowbridgii*
Vagrant shrew	*Sorex vagrans*
Virginia opossum	*Didelphis marsupialis*
Western red-backed vole	*Clethrionomys californicus*
Western spotted skunk	*Spilogale gracilis*
Western toad	*Bufo boreas*